Automatic Control LAB.
EngM513
Laboratory User's manual
Version I

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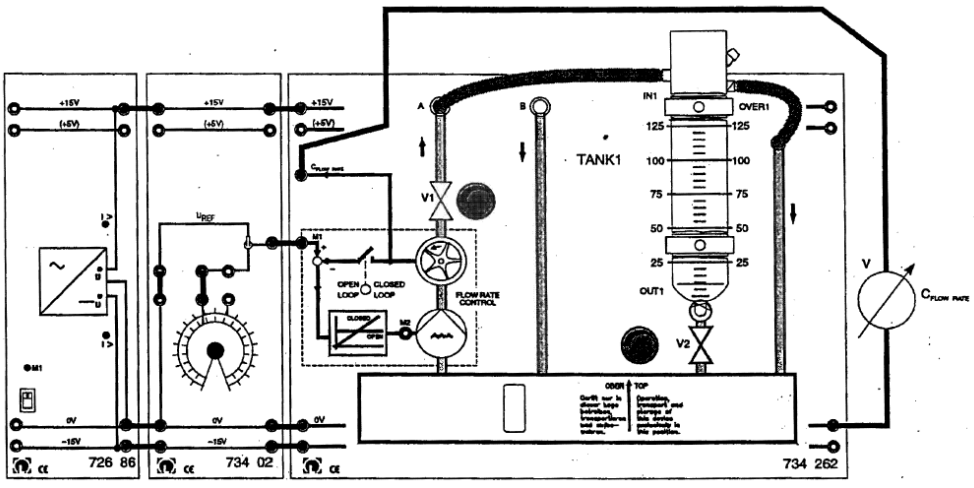
Experiment /Test No.(1)

Title: Automatic flow-rate control (Steady State Response)

Experiment/Test Description
Test Description: Recording the characteristics in open- and closed-loop operation
Test Objectives: Adhere to the basic rules for recording static characteristics.
Theoretical Background: Using a static transfer characteristic as the graphic representation of the function y = f(x) the most optimum operating range of the controlled system and its proportional-action transfer response can be determined. The most important steps are listed as follows: - Only record the measured value after the transient reactions have disappeared. - Always change only one parameter at a time, keep the other parameters constant.

Experiment/Test Activities
Equipment and tools: Equipment of the experiment: Liquid controlled system (Module # 734 262) , Power supply unit ±15V. 3A (Module # 726 86), Analog multimeter, Reference variable generator (Module # 734 02), Profi-CASSY (Module # 524019), WinFACT® Software. Recommended Extras: Universal data acquisition, PID controller



Experiment set-up for the recording of the steady state characteristic of the liquid controlled system

Test Procedure:

Steady-state system response, recording the static characteristic:

1. Assemble the experiment set-up in accordance with Figure,

2. Open the valve V1 completely.

3. Set the reference variable generator to the values specified in the table and wait until a constant value for the flow-rate is produced. Make a note of the $C_{Flow\ Rate}$ value in the Table.

4. Plot the value pairs, by connecting up the measured values you obtain

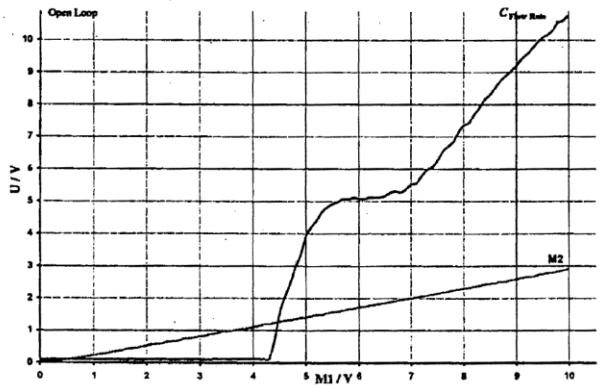
5. Determine the value or values of Ks from the Note: characteristic (gradient of the characteristic into the "defined" operating range).

6. Repeat steps 3 and 4 for the case of the closed control loop (set the switch to Closed Loop). Enter the measured values into the table.

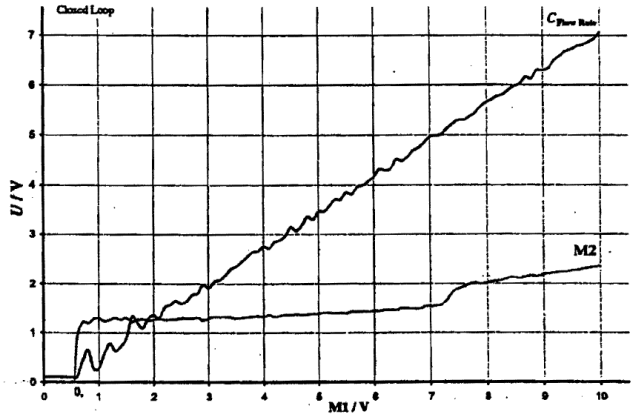
Test Results:

Table: Steady-state characteristics for:"Open Loop" and "Closed Loop"

	Loop Open	Loop Closed
$\frac{M1}{V}$	$\frac{C_{Flow\ Rate}}{V}$	$\frac{C_{Flow\ Rate}}{V}$
0	0.0	0.0
1	0.0	0.3
2	0.0	1.4
3	0.0	1.9
4	0.0	2.8
5	3.9	3.5
6	5.1	4.2
7	5.5	5.0
8	7.3	5.7
9	9.2	6.3
10	10.7	7.1



Steady-state characteristic in the open-loop operating mode



Steady-state characteristic in closed-loop control mode

Conclusion:

- The static -characteristic in open-loop operation is non-linear, i.e., it does not have a constant gradient and it has a dead zone from 0 up to approx. 4.3 V.

- Because of the internal feedback -the characteristic is linearized and the dead zone severely reduced (however, for low voltages the control loop tends to oscillate and the compensation times become increasingly longer).

Comments:

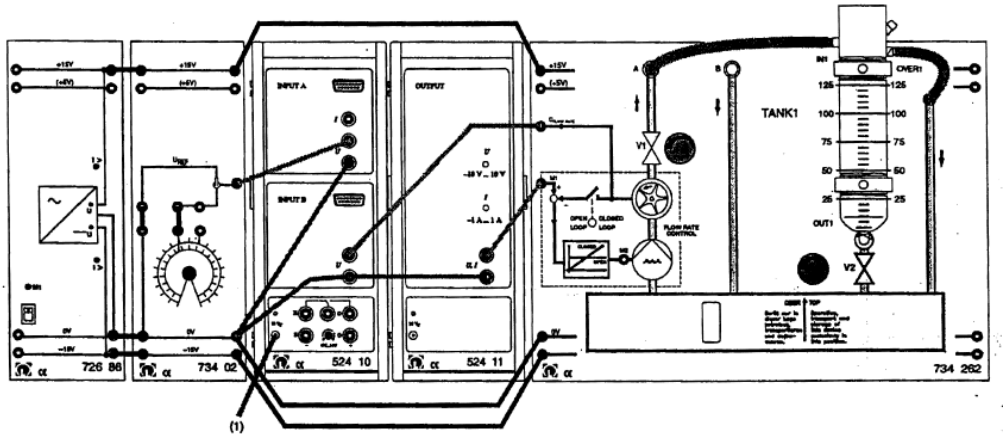
A CASSY interface can used If you have an XY recorder or a CASSY interface at your disposal, you can use these to record the characteristics. The CASSY system is particularly well-suited for evaluation and display of measurement values because of its many setting options. these to record the characteristics. The CASSY system is particularly well-suited for evaluation and display of measurement values because of its many setting options.

Experiment /Test No.(2)

Title: Automatic flow-rate control (Dynamic System Response)

Experiment/Test Description
Test Description: Dynamic system response of flow rate control: recording of the step response (reference or set-point step change)
Test Objectives: Emphasis to reach the set-point or desired value of the control system as fast as possible with either no or very little control deviation.
Theoretical Background: - Solution of the first order system (Lecture), S-shape response (Lecture) - Open loop control (Lecture), - Closed loop control (Lecture).

Experiment/Test Activities
Equipment and tools: Equipment of the experiment: Liquid controlled system (Module # 734 262) , Power supply unit ±15V. 3A (Module # 726 86), Analog multimeter, Reference variable generator (Module # 734 02), Profi-CASSY (Module # 524/10/11/19), WinFACT® Software. Recommended Extras: Universal data acquisition, PID controller



Experiment set-up for the recording of the steady state characteristic of the liquid controlled system

Test Procedure:

Determining the system parameters on the open control loop:

1. Assemble the experiment set-up in accordance to the Figure.

2. Use the automatic control software WinFACT® for the recording of the step response. Set the reference variable to Ml = 10 V, set the switch to Open Loop.

3. Determine the time delay and compensation time T_{il} and T_g of the system.

4. Modify the experiment set-up by integrating an external controller (CASSY or the PID controller) into ,the experiment set-up. 'Set ' the selection switch to Open Loop.

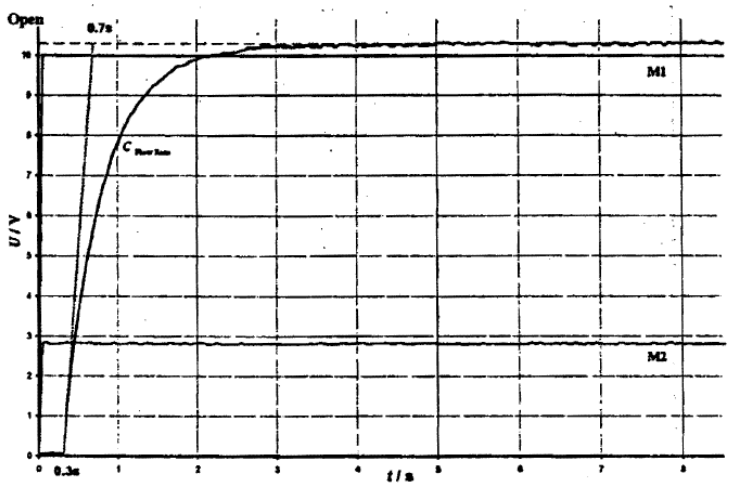
5. Experiment 'with: different controller types (P, PI, PID). and ,controller settings and observe their effects on the step response.

6. Remove the external controller. Set the selection switch to Closed Loop and record the system's step response.

7. Compare, the control response during internal and external automatic control operation.

Test Results:

- With the system parameters (Ks from the steady-state characteristic); K_s = 2.0, T_u= 0.3s, T_g=0.4 s



Reference step response, open control loop

Conclusion:

- With the system parameters (K_s from the static characteristic) the controller parameters are obtained according to good reference response, no overshoot

Comments:

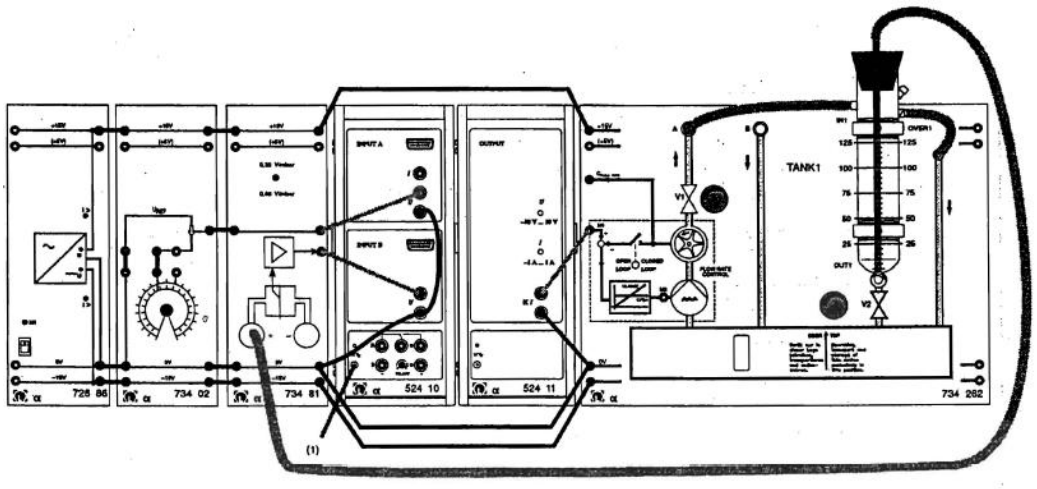
It is the aim of each automatic control to reach the set-point or desired value as fast as possible with either no or very little control deviation. A comparison of control characteristics can be carried out by investigating the various transient responses.

Experiment /Test No.(3)

Title: Automatic liquid level control

Experiment/Test Description
Test Description: To perform automatic liquid level control upon single capacitance dynamic system.
Test Objectives: - Training upon controlling the liquid level system is carried out. - The effect of pneumatic feedback is demonstrated and the measures needed for the head level are explained. - Closed control loop is implemented by adjusting the proportional gain.
Theoretical Background: Liquid level measurement: in order to control the liquid level, it must be converted into an electrical signal. As the pressure exerted on the floor of the tank is proportional to the height of the liquid level, pressure measurement is a suitable procedure to determine the liquid level. Due to the fact that the pressure at the floor of the reservoir is the product composed of the pressure of the liquid column and the atmospheric pressure, a differential pressure transducer is used whose first input receives the pressure from the tank floor and whose second input receives the atmospheric pressure.

Experiment/Test Activities
Equipment and tools: Equipment of the experiment: Liquid controlled system (Module # 734 262) , Power supply unit ±15V. 3A (Module # 726 86), Analog multimeter, Reference variable generator (Module # 734 02), Profi-CASSY (Module # 524/10/11/19), WinFACT® Software. Immersion tube (Module # 734 876), Differential pressure transducer (Module # 734 81). Recommended Extras: Universal data acquisition, PID controller

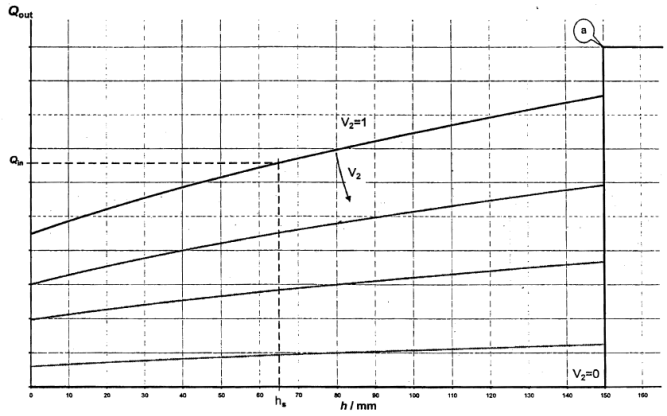


Experiment set-up:+ immersion tube + differential pressure transducer

Test Procedure:

- The system features can be manipulated using the valves Vl , V2 and the reference variable generator Ml. The inlet flow Q_{in} is caused by Ml and V1 and the outlet flow Q_{out} by V2. If V2 is closed completely, for example, the system demonstrates integration behavior and then constitutes a system without compensation (only overflow restricts the liquid level and serves as a limiting facility).

- As the outflow or drain off Q_{out} is a function of the level height h (the outflow rises with increasing level height), a steady-state level h_s settles in, where inlet and outlet flows are in equilibrium. The Figure illustrates this relationship qualitatively (V2 = 1 : Valve V2. completely opened; V2 =0 : Valve V2 completely closed). If Q_{out} is too low or Q_{in} is too high, h_s lies above the overflow edge. In this case h_s cannot be reached.



Qualitative representation of the drain or outlet flow as a function of the liquid level height (a): overflow

- For h = 0 there exists a value of Q_{out} other than zero because the outlet opening permits a certain amount of drain or outlet flow dependent on V2.

- The maximum liquid level achievable by the automatic control, as a function of the valve setting V2, is obtained by the steady-state level at an Ml setting of 10 V (maximum manipulated variable of the liquid level controller).

Steady-state system response: Setting of valve V2

1. Set up the experiment in accordance with Figure,

2. For M1 = 5 V set the valve V2 in such a fashion that a steady-state level h_s of approx. 80 ... 90 mm sets in.

3. Using the valve setting for V2from sub-point 2 the steady-state level h_s is recorded as a function of the input variable M1. For this set the values of M1 specified in a Table 5.1 and note down the values of h_s which settle in (careful: slow compensation processes).

4. Plot the value pairs Ml and U_{hs} into a chart and draw the characteristic. Determine the gradient (proportional- action coefficient Ks) of the characteristic in the operating range of interest.

Dynamic system response, reference variable step change

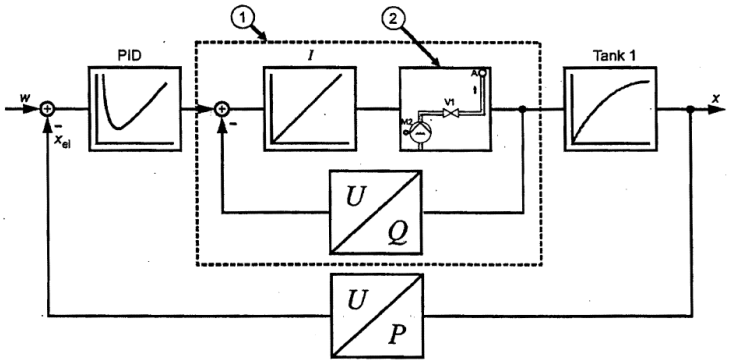
Determining the system parameters of an open liquid level control loop

5. Use the automatic control technology software WinFACT® to record the step response (for operating instructions refer to the WinFACT® user manual).

Reference variable step change to Ml = 5 V; Set the switch to "Closed Loop"; valve setting V2 from sub-point 2.

Test Results:

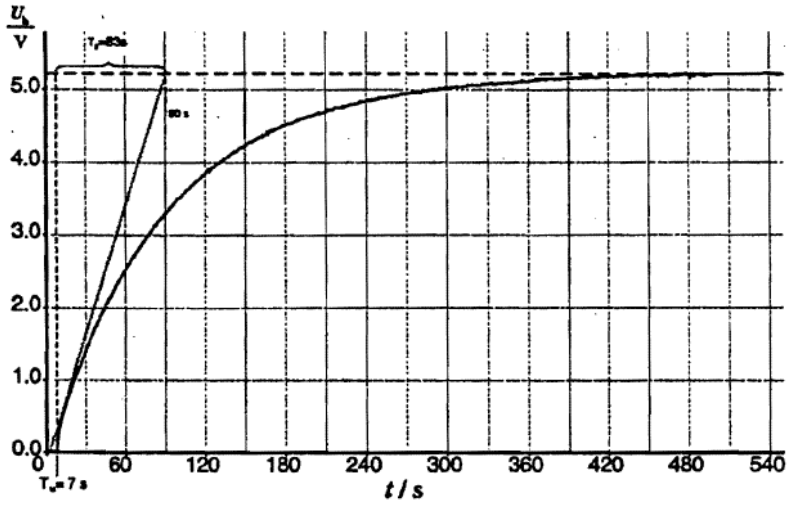
The block diagram of the system can be illustrated as shown in the following Figure,



Block circuit diagram o/the automatic liquid level control with cascade flow-rate control

(1): Cascade flow-rate control

(2): Flow-rate controlled system (pump, valve VI, hose to TANK1)



Step response of the open liquid level control loop: Reference variable step change to M1 = 5 V

Conclusion:

From the step response the time delay T_u and the compensation time T_g can be determined. The proportional-action coefficient K_s is determined from the steady-state characteristic.

	Ks=2.8	Tu=7 s	Tg = 83 s

Comments:

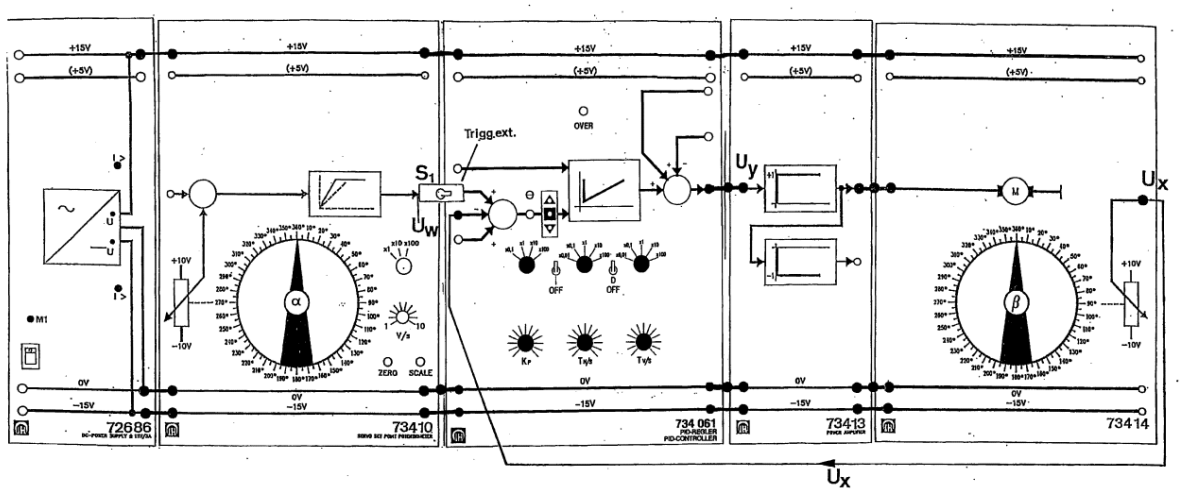
• If you want to avoid non-linearities (overflow or non-filling) in the system, then the initial step is to set the outlet valve V so that a suitable steady-state can set in. In addition a manipulated variable is set for Ml and the valve V2 is set so that a desired steady-state level h_s is reached.

Experiment /Test No.(4)

Title: Servo control of DC motor

Experiment/Test Description
Test Description: An experiment which provides an introduction to servo technology, its purposes, functional modules and machines. The DC-servo with tacho-generator is investigated, as is the influence of Kp and tacho feedback in terms of accuracy and correction time. Furthermore, in a further section of the experiment, the mass inertia ratios are altered by attaching an additional weight
Test Objectives: - Training upon operating/controlling the DC servos is carried out. The potentiometer is treated as well as the requirements for a rapid and accurate control operation. - The effect of electrical feedback is demonstrated and the measures needed for problem-free operation are explained. - Functions of a servo, Examples of application, - Output variables: torque, adjustments in angle and displacement - Closed control loop: status indication of angle or displacement,
Theoretical Background: This Servo system applications are always performed by servomotors with powers ranging from approx. 20 W to 20 kW. Fields of application: - Aerospace technology - Shipping - Robotics - Industrial and manufacturing processes, wherever positions (x, y, z), speeds or angles need to be changed. Perquisites: - Modeling of electrical system (Lecture), - Modeling of DC motors (Lecture), - Tacho-generator , speed measurement sensors, (Lecture)

Experiment/Test Activities
Equipment and tools: Equipment of the experiment: Servo set-point potentiometer (Module #73410), PID-controller (Module #734061), Power amplifier (Module #73413), DC-Servo (Module #73414), Power supply unit ± 15V 13A (Module #72486), Toggle switch, single-pole (Module #57913), Two-channel, digital-storage oscilloscope (HM 205-2 57529). Recommended Extras: Multi-meters



Experiment set-up

Test Procedure:

1. Every servo is equipped with a driving machine, e.g. a DC motor with a permanent field or a single-phase or multi-phase AC motor.

2. A step-down gear unit which slows the motor down to a useful operating speed for a variable resistor.

3. The variable resistor can have a circular shape: in this case, a torque for angular adjustment is applied to its shaft. If the variable resistor has a liner shape, adjustment must be carried out by means of a spindle. The mechanical setting of the wiper determines the displacement setting. For both systems, the following applies:

3.1. Corresponding to the magnitude of the inputs signal, for the machine, the input voltage or phase difference generated is (almost) proportional to the speed: PT-1

3.2. If the starting voltage is taken into· account, this results in a dead time, PT1-T,

3.3. Every rotation of the machine results in a control interval at the potentiometer: according to the operating duration, the potentiometer sums up the control intervals with respect to time (integral system); the length of the control intervals (dt) depends on the input values (voltage, phase) for the machine.

4. The output variable is taken from the wiper of the variable resistance used to feed back the position attained. and fed to a controller. The comparator at the input of the controller compares the feedback variable U_x, with a set-point value U_w, forms the system deviation:

$$U_{xd} = U_w - U_x$$

for the purpose of matching, i.e. it counter-adjusts ($-U_x$) until the system deviation is $U_d=0$ and the machine is no longer supplied with a manipulated variable via the control element (machine comes to a stop).

In this experimental set-up, the DC-servo in the control loop is handled as follows:

- with a P-controller: dependency of the system deviation on Kp, controlled oscillations

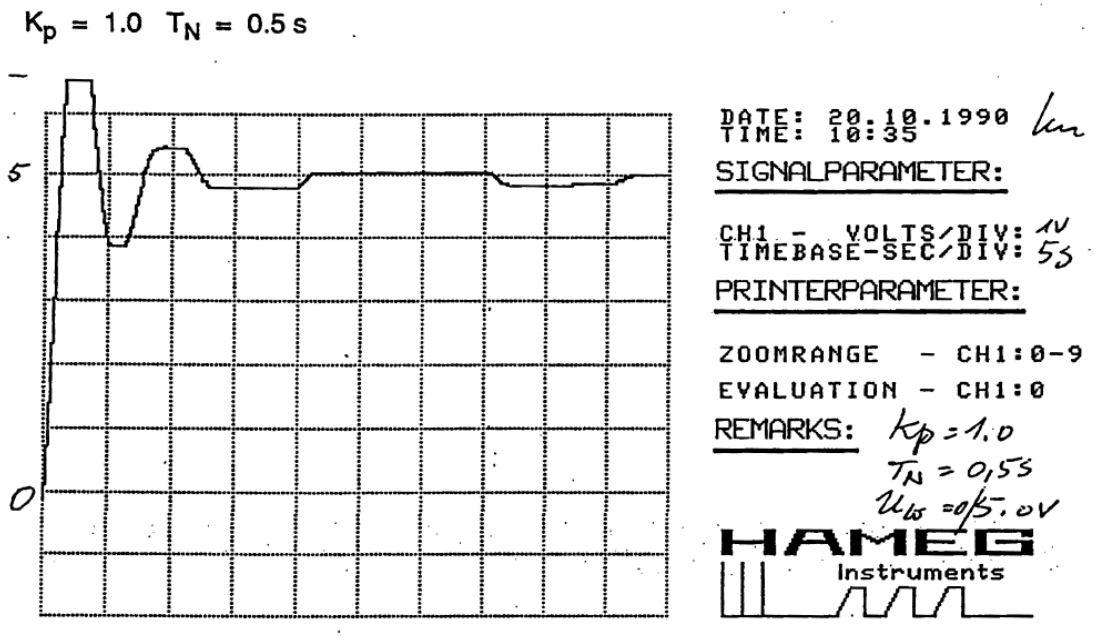
- with a PI-controller: removal of the system deviation, overshoot

- with a PID-controller: removal of the system deviation, overshoot attenuation, removal of controlled oscillations

Test Results:

- A servo system is used for transferring conditions, e.g. angles, displacements or positions applying at location, A, to location B as accurately as possible. Such accurate transfers require a closed control loop with feedback from location B: closed-loop control.

- In simpler cases: only adjustment is required at location B: this involves an open control loop without feedback



Servo Controller to DC-motor

- If the feedback variable is fed to the input summing unit with the negative sign, it is subtracted from the reference variable (set-point value). The system deviation (X_d=w-x) is formed. The system deviation forms the manipulated variable in the controller and the -control element. This variable adjusts the machine until the system deviation is X_d=0.

- If the feedback loop is removed, the control loop is opened, and the machine operates as long as a manipulated variable is applied: "open control loop"

Conclusion:

- Strong, positive overshoot, followed by overshoots of decreasing magnitude. Following a standstill or reversal in direction, compensation only-takes Place once the integrator component in Uy has reached the starting voltage.

Comments:

Depending on the results of these comparisons, the controlled variable X is adjusted to correspond with the reference variable W. In other words, a controller must:

1. measure (register, evaluate)

2. compare

3. adjust

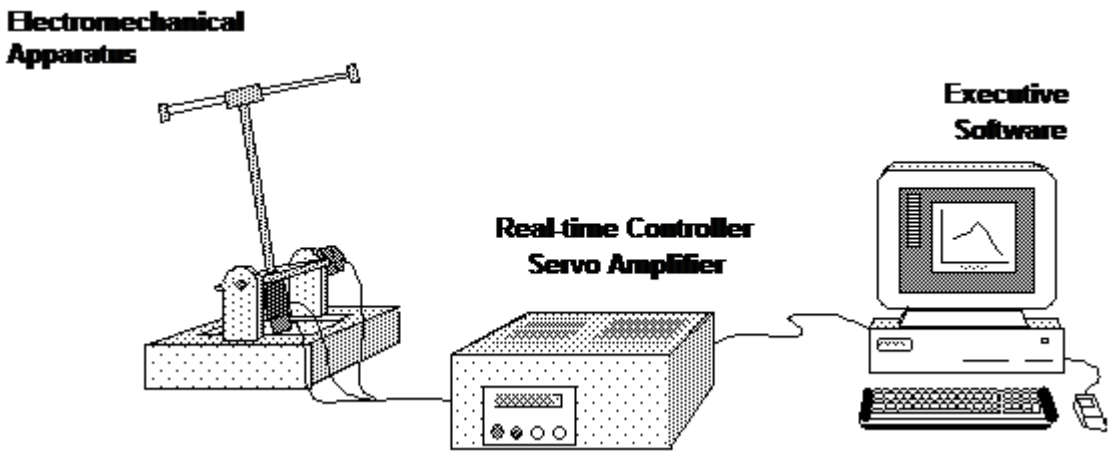
The controller registers the actual value of the controlled variable at the output of the system by means of a sensor and compares it with the set-point value. The difference is processed such that it causes a change in the manipulated variable which counteracts the deviation of the controlled variable from the set-point value.

Experiment /Test No.(5)

Title: Stabilizing Inverted pendulum

Experiment/Test Description
Test Description: This experiment steers a horizontal sliding rod in the presence of gravity to balance and control the position of the vertical ("pendulum") rod. The mechanism is open loop unstable (right half plane pole) and non-minimum phase (right half plane zero). As a result feedback control is essential for stability and the structure of the controller must be selected carefully due the non-minimum phase characteristics.
Test Objectives: - Understanding the stability criteria of the dynamic systems, - The effect of electrical feedback is demonstrated and the feedback operation is explained. - Functions of a servo-systems
Theoretical Background: - Stability criteria of mechanical systems (Lecture) - Modeling of inverted pendulum system (Lecture) - Modeling of electrical system (Lecture), - Modeling of DC motors (Lecture), - Digital Encoder , speed measurement sensors, (Lecture) - Modeling and control Servomotors (Experiment no. (3))

Experiment/Test Activities
Equipment and tools: The experimental control system is comprised of the three subsystems shown in the Figure. The first of these is the electromechanical plant which consists of the inverted pendulum mechanism, its actuator and sensors. The design features a DC servo motor, high resolution encoders, a low friction sliding balance rod, and adjustable balance weight. Next is the real-time controller unit which contains the digital signal processor (DSP) based real-time controller , servo/actuator interfaces, servo amplifier, and auxiliary power supplies. The DSP is capable of executing control laws at high sampling rates allowing the implementation to be modeled as continuous or discrete time. The controller also interprets trajectory commands and supports such functions as data acquisition, trajectory generation, and system health and safety checks. A logic gate array performs encoder pulse decoding. Two optional auxiliary digital-to-analog converters (DAC's) provide for real-time analog signal measurement. This controller is representative of modern industrial control implementation. The third subsystem is the executive program which runs on a PC under the DOS or Windows™ operating system. This menu-driven program is the user's interface to the system and supports controller specification, trajectory definition, data acquisition, plotting, system execution commands, and more. Controllers may assume a broad range of selectable block diagram topologies and dynamic order. The interface supports an assortment of features which provide a friendly yet powerful experimental environment



Experimental control system

Test Procedure:

The student must ensure the followings:

a) The ECP Executive program has been successfully installed on the PC's hard disk,

b) The actual DSP printed circuit board (the real-time Controller) has been correctly inserted into an empty slot of the PC's extension (ISA) bus (this applies to the PC bus version only).

c) The supplied 60-pin flat cable is connected between the J11 connector (the 60-pin connector) of the real-time Controller and the JMACH connector of the Control Box .

d) The other two supplied cables are connected between the Control Box and the Inverted Pendulum apparatus;

e) The Inverted Pendulum apparatus has the adjustable weight at the default height shipped from the factory.

The experiment steps:

Step 1: Switch off power to both the PC and the Control Box.

Step 2: With power still switched off to the Control Box, switch the PC power on. Enter the ECP program by double clicking on its icon (or type ">ECP" in the appropriate directory under DOS). You should see the Background Screen (see Section 2.1.3) Gently rotate the pendulum rod and later the top sliding rod by hand. You should observe some following errors and changes in encoder counts.

Step 3: If the ECP program cannot find the real-time Controller (a pop-up message will notify you if this is the case), try the Communication dialog box under the Setup menu. Select PC-bus at address 528, and click on the test button. If the real-time Controller is still not found, try increasing the timeout in 20 ms increments up to a maximum of 300 ms. If this doesn't correct the problem, switch off power to your PC and then take its cover off. With the cover removed check again for the proper insertion of the Controller card. Switch the power on again and observe the two LED lights on the Controller card. If the green LED comes on all is well; if the red LED is illuminated, you should contact ECP for further instructions. If the green LED comes on, turn off power to your PC, replace the cover and turn the power back on again. Now go back to the ECP program and you should see the positions change as you gently move the pendulum rod.

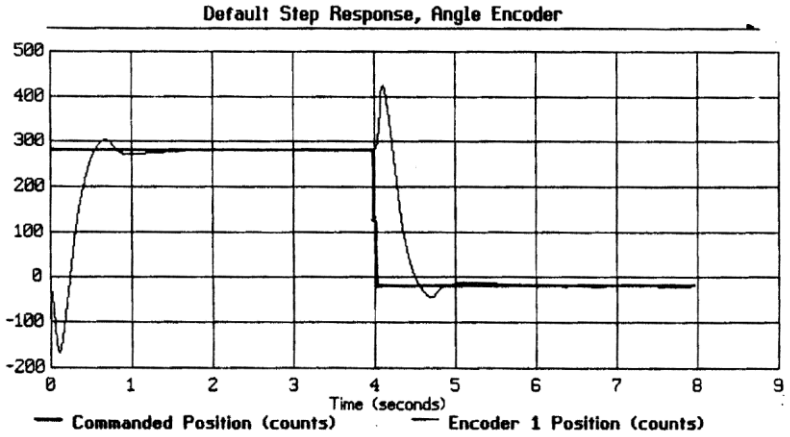
Step 4: Make sure that you can rotate the pendulum rod and move the sliding rod freely. Now connect the power cord to the Control Box and press the black "ON" button to turn on the power to the Control Box. You should notice the

green power indicator LED lit, but the motor should remain in a disabled state. Do not touch the apparatus any more, remember whenever power is applied to the Control Box there is a potential for uncontrolled motion of the pendulum.

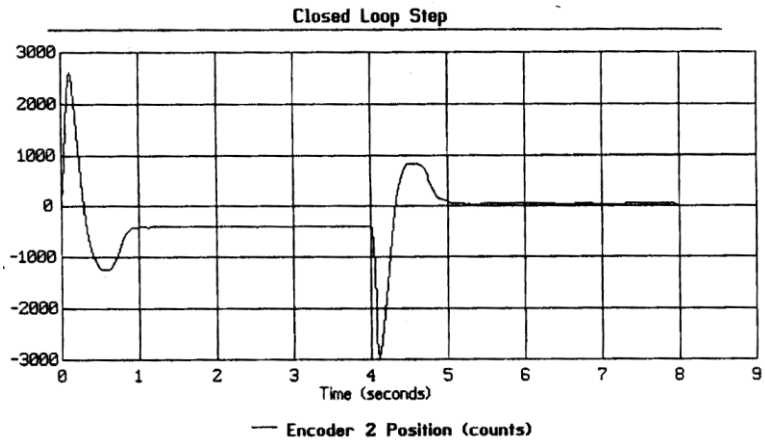
Step 5: Now turn off the power to your PC.

Step 6: Now enter the Setup menu and choose, Setup Control Algorithm option. You should see the sampling time Ts = 0.00884 seconds, Time control, and the General Form button selected. Now select Setup Algorithm and you should see the following gains: T0=2.5, S0=24.61, S1=-24.00, H0=1,0 I0=1.8427, I1=-1.76, E0=0.35, and G1=-0.5. This controller was designed using the linear quadratic regulator technique with all error weighting on encoder #1 (the pendulum angle encoder). In addition, a low pass filter was included (G1 coefficient) to reduce quantization noise.

Step 7: Exit this dialog box and, with the pendulum in the vertical position and the sliding rod in its middle "T" position, select Implement Algorithm. The control law is now downloaded to the real-time Controller. Very gently push the pendulum rod with the ruler to verify that control action is in effect. If you do not notice any motor power, use the ruler to move it back to the vertical position and then, click on the Implement Algorithm button again until you notice the servo loop closed. Now select Upload Algorithm, then General Form and Setup Algorithm. You should see the same coefficients uploaded back from the real-time controller to the Executive program. Note that the general form algorithm is the only structure that actually runs in real-time. All other structures (e.g. PID etc.) are translated to the general form by the Executive prior to implementation.



Step Response at Angle Encoder (#1)



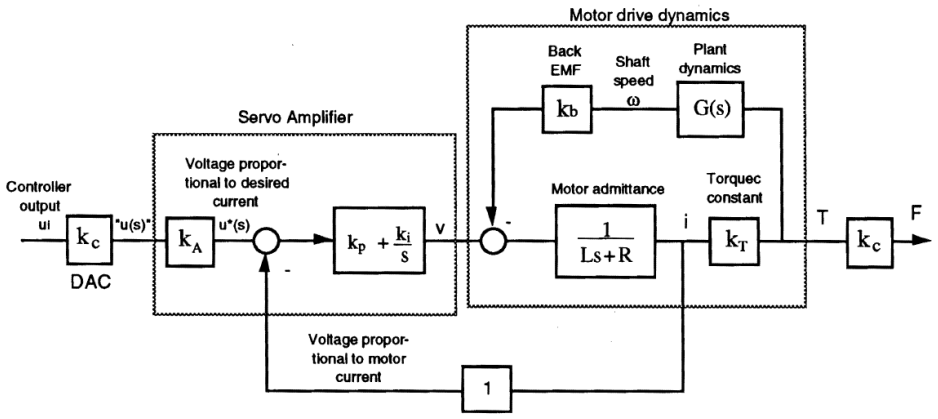
Step Response at Sliding Rod Encoder (#2)

Step 8: Enter the Command menu and select Trajectory. In this box select Step and then Setup. You should see step size = 300 counts, dwell time =4000 ms and no. of repetitions =1. If not, change the values to this parameter set. Exit this box and go to the Command menu. This time select Execute and with the Sample Data box checked run the trajectory. You should have noticed a step move of 300 counts, a dwell of 4 second and a return step move. Wait for the data to be uploaded from the real-time Controller to the Executive program running on the PC. Now enter the Plotting menu and choose Setup Plot. Select Encoder 1 and Commanded Position for plotting (left axis) and select Plot Data.

- A plot similar to the one shown in previous Figure is generated. Replace Encoder 1 with 2 via the Setup Plot box and then plot data. A similar plot to the one shown in Figures should be seen. Notice the initial reverse motion which is a characteristic of a non-minimum phase plant. This phenomenon is explained from basic laws of dynamics.

Test Results:

With the control system of an inverted pendulum, as shown in the Figure, it can be concluded that:



Mechanism Drive Block Diagram

Servo loop closure involves computing the control algorithm at the sampling time. The real-time Controller executes the General Form equation of the control law at each sample period Ts. This period can be as short as 0.000884 seconds (approx. 1.1 KHz) or any multiple of this number. The Executive program's Setup Control Algorithm dialog box allows the user to alter the sampling period. All forms of control laws are automatically translated by the Executive program to the General Form prior to downloading ("implementing") to the Controller. The General Form uses 96-bit real number (48-bit integer and 48-bit fractional) arithmetic for the computation of the control effort. The control effort is saturated in software at +/- 16384 to represent +/- 5 volts on the 16-bit DACs whose range is +/- 10 volts. The +/-5 volt limitation is due to the actuator 's amplifier input voltage scaling.

Conclusion:

The control designs given here are in no sense optimized, but rather are designed to demonstrate several fundamental principles of control. The student can implement other designs or invent other approaches, such:

a) Feed-forward design for improved tracking performance is readily implemented through the Setup Feed-forward box under Setup Control Algorithm.

b) Trajectories may be optimized for characteristics such as rapid response, minimum tracking error, or minimum peak control effort. The user may select from the library of geometric trajectories, or develop and implement custom shapes via User Defined in the Trajectory Configuration dialog box.

Comments:

There are two incremental rotary shaft encoders used in the inverted pendulum . These are used to sense the position and velocity of the pendulum rod and the sliding rod. The pendulum angle encoder has a resolution of 4000 counts per revolution. The sliding rod encoder (connected to the motor) has a resolution of 500 counts per revolution which is equivalent to approximately 12500 counts per meter of the sliding rod travel. (the actual sliding rod travels approximately 0.24 meter).

The encoders are all optical type whose principle of operation is depicted. A low power light source is used to generate two 90 degrees out of phase sinusoidal signals on the detectors as the moving plate rotates with respect to the stationary plate. These signals are then squared up and amplified in order to generate quadrate logic level signals suitable for input to the programmable gate array on the real-time Controller. The gate array uses the A and B channel phasing to decode direction and detects the rising and falling edge of each to generate 4x resolution. (Hence the effective encoder resolution is 16,000 counts/rev. and 50200 counts/m for the respective pendulum and balance rod measurements.) The pulses are accumulated continuously within 24-bit counters (hardware registers). The contents of the counters are read by the DSP once every servo (or commutation) cycle time and extended to 48-bit word length for high precision numerical processing.

Experiment /Test No.(6)

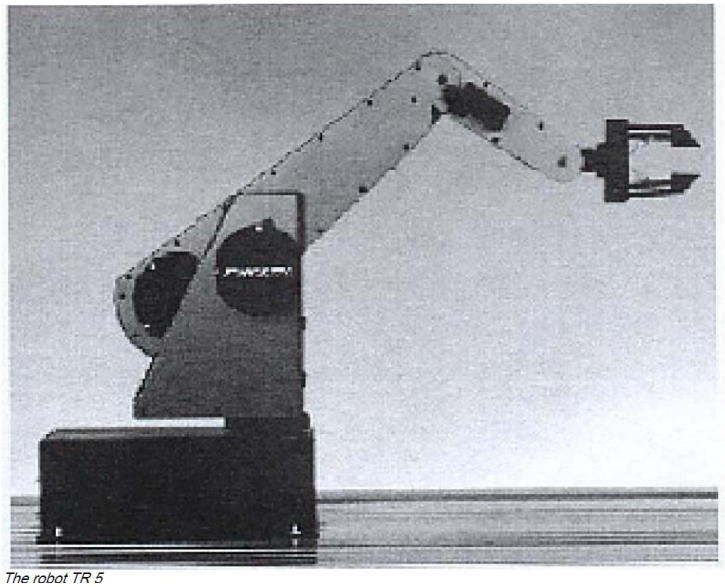
Title: Robot Control (Position control of DC servos)

Experiment/Test Description
Test Description: This training articulated arm robot has 5 rotary axes and a parallel gripper giving several application possibilities. As the controller is integrated in the base of the robot, an easy and fast installation and implementation can be assured. A quick access to the programming is enabled by the software "LD-Rob" delivered with the robotTR5. The students are going to use the TR5 robotic arm to feed working pieces into sorting station. the student is asked to write a program using the "LDrob" software and to use the I/O signals from both the station and the robot to synchronize the process.
Test Objectives: - Understanding single-input/multi-output feedback control system. - Functions of a servo-systems, DC motors with potentiometric position transducers.
Theoretical Background: - Modeling of DC motors (Lecture), - Potentiometer position measurement sensors, (Lecture) - Modeling and control Servomotors (Experiment no. (3)) - Introduction to Inverse Kinematic Position Modeling (IKPM).

Experiment/Test Activities
Equipment and tools: - The mechanical structure of the TR 5 consists of aluminum parts screwed together. Each of the five independent axes is driven by a DC Servo-motor. At axes no. 1,2, and 5 power transmission is assured by toothed-gears. For power transmission at axes 3 and 4, one toothed belt each is used in addition. The absolute positions of all axes are determined by potentiometric position transducers. This out-standing feature of the TR 5 guarantees that even after the switch-on of the unit the robot controller knows the exact current position of each single axis. Thus, tiresome reference runs are no longer necessary. - The controller is integrated in the base of the robot. An 8031 processor is the heart of the controller. In the PtP (point-to-point) mode, movements of single axes or even of more axes at the same time can be realised. User programmes can be stored in a battery-backed-up RAM. Memory capacity is 8 KB, this corresponds to approximately 1000 program steps. In addition, the robot can be connected with a PC via an RS 232 interface. 8 digital, TTL-compatible inputs and outputs are at the user's disposal through a parallel port connector. - The gripper is powered by a DC Servo-motor via a spring-mounted cable. Thanks to this structure, the gripper position as well as the gripping force are freely-programmable. In addition, the extremely wide stroke of 60 mm permits the handling of a wide variety of pieces without making modifications at the gripper fingers necessary. - I/O-Adaptor/Simulator :For communication with the robot TR5 the I/O-Adaptor/ Simulator (728110) can be used. This I/O-Adaptor/Simulator can be used to send or receive binary signals, for example start or stop commands, to the robot TR5. The I/O-Adaptor/Simulator has the following features: • 8 digital inputs (4-mm sockets), TTL-compatible, overvoltage proof up to 30 V • 8 digital outputs (4-mm sockets), 5 V TTL/24 V PLC with LED display • 1 input for external stop (4-mm socket) I/O simulator

• 8 stay put/spring return switches for input assignment

• 1 pushbutton with holding function



The robot TR 5

Training Robot

To work with TR 5 you need at least:

• The TR 5 (training robot)

• The power supply unit with two power leads (red/black)

• The RS-232 shorting connector

• The LD-Rob Software

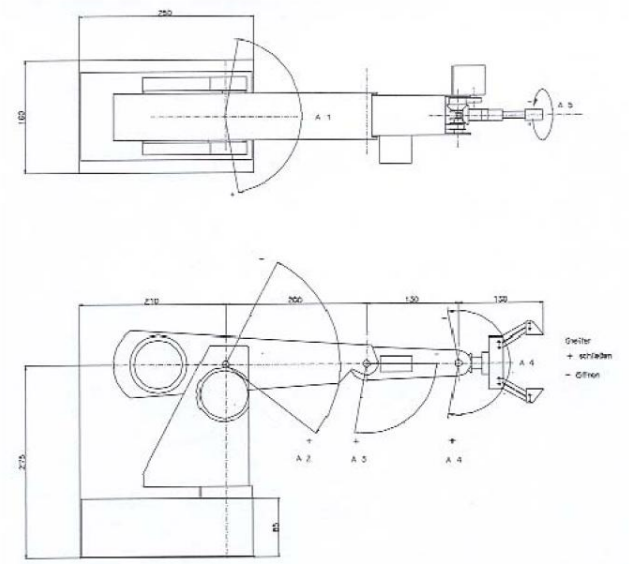
The technical specification of the robot arms/motors are listed in the following Table,

Technical Specifications

MECHANICS	
Kinematics	5-axis link arm robot
Drive systems	DC Servo-motors
Position detection	absolute, potentiometric
Working ranges: Axis 1 (base) Axis 2 (shoulder) Axis 3 (elbow) Axis 4 (wrist) Axis 5 (tool) Gripper	 160° 100° 100° 200° 200° 60mm
Gripper	electric parallel gripper stroke 0-60 mm, position and gripping force freely programmable (standard version)
Max. payload	250 g
Repeatability	+/- 1 mm
Resolution: Axis 1 Axis 2 Axis 3 Axis 4 Axis 5 Gripper	 256 increments 256 increments 256 increments 256 increments 256 increments 256 increments
Max. joint speeds: Axis 1 Axis 2 Axis 3 Axis 4 Axis 5	 46 degrees/sec. 40 degrees/sec. 100 degrees/sec. 174 degrees/sec. 176 degrees/sec.
Total weight:	approx. 6 kg (including controller)

Test Procedure:

Regarding the kinematics problem, see the Figure, the students should calculate the angles of the motors in the start (home) point and in the final point,



The experiment steps:

Step 1: Installation of the software

The installation of the LD-Rob Software is started by starting the program "setup" on the CD delivered with the robot TR5. Please follow the instructions of the installation shield.

Step 2: Installation of the hardware :

- Connect the TR 5 to the power supply unit with the two power leads.
- Turn the power switch to ON, press the HALT key on the I/O-Adaptor/Simulator and press the RESET key on the TR 5.

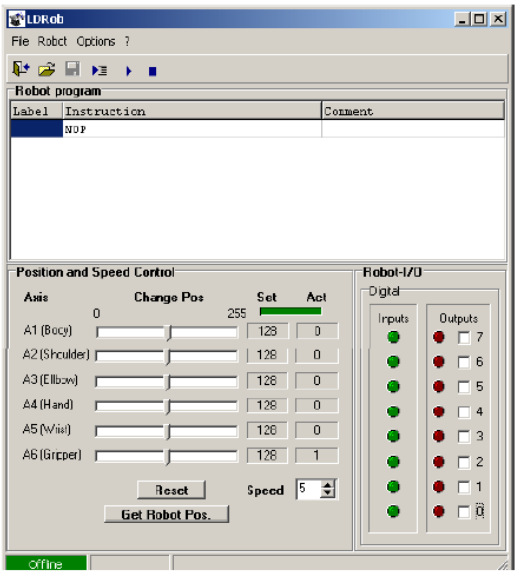
Step 3: The LD-Rob Software:

After starting the software, you see can the window of the LD-Rob software, that is shown in the figure below. By using this software the robot TR5 can either be programmed or controlled manually.

Controlling the robot manually can be useful to test the hardware of the robot or to drive the robot for checking a position you want to program.

The parts of this window will be described in the following. You can find a detailed description of the software in the document "LDRob-help.pdf".

In the left bottom corner you can see if the robot in online, i.e. if there is a communication between the robot and the computer. If the robot is offline click on Robot->Init.



TR5 software

Step 8: write the program as follows:

Position and Speed Control:

- The six axis of the robot arm are: A1 (Body), A2 (Shoulder), A3 (Elbow), A4 (Hand), A5 (Wrist) and A6 (Gripper).

- In manual mode (no robot program is running) they can be manually controlled by the six track bars in this field.

- The track bars change the set value of the corresponding axis. If the robot is online, it will follow this set point by activating the appropriate drive. Set and actual values are displayed beneath the trackbars. When all axis have reached their set position, the green "LED" will light up.

- Speed can be selected independently in the range 1..5

- The button Reset sets all set values to 128 and the speed to 5 (maximum).

- With Get Robot Position it is possible to read the actual positions back from the robot.

Robot-I/O

- As long as the robot is online, the LEDs in this field show the actual states of the digital inputs and outputs of the

robot base. In order to change the state of a digital output the checkbox beneath the corresponding output LED can be used.

Robot program

- In this part of the window you can program the robot TR5. The appropriate entries of the context menu (right-click or key F10) can be used to add, insert or delete an instruction line.The instruction set of the robot TR5 consists of the following instructions:

NOP, POS, OUT

TIME, WAIT, IF

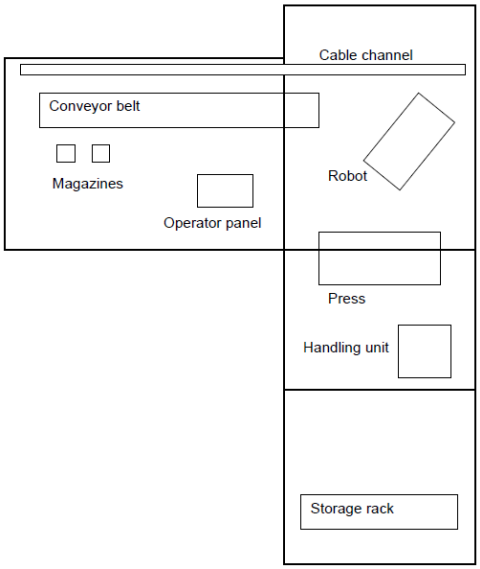
GOTO, LOOP, HALT

The TR 5 program memory is non-volatile, and is powered by a long-life lithium battery; your programs will remain stored in the robot's memory for around 10 years, even when the mains power is switched off.

```
Labels    Instructions                  Comments

Init      POS 100 100  50  66  31   0  SP:5    Initial Position
Start     WAIT FOR DI3 = 0                     Wait for a WP from the Buffer
          POS 255  30  50  10  78   0  SP:5    Go to buffer
          TIME 500 ms                          Wait 0.5 second
          POS 255  30  50  10  78 255  SP:5    Close Gripper
          POS 100 100  50  66  31 255  SP:5    Go to the initial position
          OUT DO0 1                            Alert Sorting Station for a WP
          WAIT FOR DI0 = 0                     Wait for the sorting station to be ready
          OUT DO0 0
          POS  20  40  50 250 214 255  SP:5    Move to the beginning of the conveyor
          TIME 500 ms                          Wait 0.5 second
          POS  20  40  50 250 214   0  SP:5    Drop the WP on the Conveyor
          TIME 500 ms
          POS  50  60 100 200  70   0  SP:5    Move away from the conveyor
          OUT DO1 1                            Tell the Sorting to start working
          GOTO Init                            Start Again
```

Test Results: Regarding the geometry of the automation line, the reference values of the motors are calculated and programmed,



Automation Line

The robots follow the pre-described trajectory because of the feedback control system implemented over its motors.

Conclusion:

Servomotors are widely used in the Robotics applications, due to the required accuracy and repeatability.

Comments: